The influence of massive stars in the interstellar medium of IC 1613: the supernova remnant S8 and the nebula S3 associated with a WO star.

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ABSTRACT

We present a detailed kinematical analysis of two selected nebulae in the Local Group irregular galaxy IC 1613. The nebulae are: S8 (Sandage 1971), the only known supernova remnant in this galaxy, and S3, a Wolf-Rayet nebula associated with the only WO star in this galaxy. For S8, we have obtained and analyzed its radial velocity field, where we found complex profiles which can be fitted by several velocity components. These profiles also show the presence of high velocity, low density gas. From this, we have obtained the expansion velocity, estimated the preshock density and calculated the basic kinematical parameters of this SNR. We suggest that in S8 we are seing a SNR partially hidden by dust. This suggestion comes from the fact that the SNR is located between two superbubbles where a ridge of obscured material unveils the existence of dust. Moreover, we show that this hypothesis prevails when energetic arguments are taken into account. In the case of S3, this nebula shows bipolar structure. By means of its kinematics, we have analyzed its two lobes, the "waist", as well as its relation with the nearest superbubbles. For the first time we are able to see closed the NW lobe, showing a clover leaf shape. This fact allows a better quantitative knowledge of the nebula as a whole. Furthermore, we found evidence of an expansion motion in the NW lobe. In the light of our results, we can express that these nebulae are the product of very massive stellar evolution. It is surprising the influence these stars still have in shaping their surrounding gas, and on the energy liberation towards the interstellar medium of this galaxy.

Subject headings: Galaxies: irregular – Galaxies: individual: IC 1613 – Galaxies: ISM – Local Group – ISM: kinematics and dynamics – ISM: bubbles – ISM: supernova remnants – ISM: individual objects: Sandage 3– ISM: individual objects: Sandage 8

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1. Introduction

The irregular galaxy IC 1613 is a faint galaxy of the Local Group located at a distance of 725 kpc (Freedman 1988a, b). Because of its proximity, it is an exceptional target for the study of the interrelationship between gas and stars within this galaxy.

In two previous studies on this galaxy (Valdez-Gutiérrez et al. 2000 (hereafter Paper II) and Georgiev et al. 1999 (hereafter Paper I)) we have discovered, by means of Hα and $[SII]$ Fabry-Perot interferometry, that the ionized gas is distributed in large diameter, expanding, ring-shaped structures (superbubbles) which cover the whole optical dimension of the galaxy. Moreover, the NE region of this galaxy contains the brightest superbubbles and it is assumed that very recent star formation is concentrated in this region rich in gas. The superbubbles found outside this region are dimmer, indicating that the gas is much less dense there.

As studied in Paper I and in Hodge (1978) by means of color-magnitude diagrams of the stellar associations, we have also shown that the superbubbles are physically linked to massive star associations and that they are systematically older than the dynamical ages of the superbubbles. This fact, and some energy considerations, are indicative that the detected superbubbles are formed by the combined action of winds and supernovae explosions of the more massive stars of the interior associations. However, the supernova explosions traces cannot be detected in the classical ways, because they are too old according to the dynamical timescales of the superbubbles.

These previous studies allow us to present an overview on the relationship between stars and gas in IC 1613. However, we thought it worth to study in detail some of the nebulae of this galaxy, taking into account their environment. There are two nebulae of IC 1613 that revealed to be very interesting: the only supernova remnant detected in this galaxy, the supernova remnant Sandage 8, S8, located at the NE region of IC 1613, and the nebula hosting the only Wolf-Rayet star detected in this galaxy, Sandage 3 (Sandage, 1971), S3, located at the south and outside the NE quadrant. In this work we study the kinematics of the ionized gas in these nebulae.

2. Observations and data reduction

The observations were carried out with the UNAM Scanning Fabry-Perot (FP) interferometer PUMA (Rosado et al. 1995) on December 5-6 1996 and November 15 1998. This instrument is currently in use at the f/7.9 Ritchey-Chretien focus of the 2.1 m telescope at the Observatorio Astronómico Nacional at San Pedro Mártir, B.C., México. These observations are the same that we used in our study of the HII region and superbubble kinematics (Paper II).

In the same way, the photometric calibration of the nebulae was carried out as described in Paper II where Hα surface brightnesses and fluxes of the selected nebulae are listed in Table 4 of that work. The fluxes amount to 2.88 $\times 10^{-13}$ and 7.24 $\times 10^{-13}$ ergs cm^{-2} s^{-1} for S8 and S3, respectively, with an error of about 20 %.

3. The Supernova Remnant S8 in IC 1613.

This supernova remnant (SNR) is the only object of this class known in IC 1613. It is located in the complex of bright superbubbles in the NE region of this galaxy and studied in Paper II. Indeed, it is seen projected within superbubbles R9 and R10 (at the boundary of this latter), following the notation of Paper II, and in the vicinity of R4. It appears catalogued by Sandage (1971) as S8, by Hodge et al. (1990) as the HII region number 49 and in Paper II as N18. Its nature as SNR has been established on the following grounds. Indeed, its optical emission shows high [SII]/Hα line-ratios (d'Odorico, Dopita & Benvenuti 1980, Peimbert, Bohigas & Torres-Peimbert 1988), it has a non-thermal radio spectrum (Dickel, d'Odorico & Silverman 1985), it is an extended source of X-ray emission and it shows important velocity gradients and internal motions in its radial velocity field derived from the Hα line (Lozinskaya et al. 1998). This latter work, corresponding to a remarkable and complete multi-wavelength study of S8, also gives the internal motions of this SNR revealing the existence of several velocity components in the SNR's radial velocity profiles. According to Lozinskaya et al. (1998), the main component appears to be quite broad ($FWHM = 270 \pm 3$ km s^{-1}) and shows a systematic velocity gradient from –290 km s^{-1} to the east to –340 km s^{-1} to the west of S8 (heliocentric velocities).

However, from the analysis of the radial velocity field and/or broadenings of the several velocity com-

ponents, these authors do not find any direct indication of an expanding shell motion. Indeed, there is no indication of a variation of the difference in velocities of the components nor in the broadenings of the velocity components from the center to the boundaries, characteristic of radial expanding shells. Given that S8 is one of the most conspicuous nebulae in our kinematic observations of IC 1613 and that our observations have better spectral resolution (35 versus 114 km s^{-1}) and similar spatial resolution as those of Lozinskaya et al. (1998), we undertook the study of the detailed radial velocity field of S8 with the aim to find some direct evidence of expansion from our kinematic data.

Figures 1 and 2 show the location of S8 relative to the bright network of expanding superbubbles studied in Paper II and also, the location of the Wolf-Rayet nebula S3 that we will discuss in Section 4. Figure 1 shows the field at Hα while Figure 2 at [SII]. The images correspond to the FP velocity maps in Hα and [SII] at the heliocentric velocity of –253 km s^{-1}. Two bright and small HII regions, Sandage (1971) regions S7 and S6, are located near the SNR to the north and the NW, respectively. The SNR S8 and the HII regions S7 and S6 appear located at the boundary of the superbubble R10 (catalogued in Paper II). It is interesting to note also that between the superbubbles R4 from one side and R9 and R10 from the other side, a ridge of obscured material is detected suggesting the presence of dust.

Figure 3 shows a close-up of the SNR emission at Hα. The S8 region is seen as having dimensions of 8$''$ $\times$ 6$''$ (corresponding to a mean linear radius of about 12 pc at a distance of 725 kpc). It is possible that due to the low angular resolution, no filamentary structure is detected. The brightness distribution has a peak toward the center instead of limb-brightening as it is expected for shell-type SNRs. On the other hand, the spectral index of the nonthermal radio emission is $\alpha = -\ 0.6$, typical of shell-type SNRs. Therefore, it is possible that S8 is only the brightest part of a larger diameter shell-type SNR that extends further to the NE, quite near the intersection of superbubbles R4 and R9, where a dust ridge is suggested.

The presence of dust there can dim the possible optical and X-ray emission below the detection limits. It is interesting to note that in the VLA observations of Lozinskaya et al. (1998) the SNR is located at the northern edge of their field and consequently, these radio observations did not cover the NE field where the hypothetical other part of the shell could be located. A nearer equivalent to the SNR S8 would be the SNR N63A in the LMC (Chu et al. 1999). N63A is seen projected within the boundaries of the superbubble N63 of larger dimensions. In the case of N63A, the bright optical emission only occupies about the northwestern quarter of the true SNR extent revealed by X-rays and radio-continuum emissions. However, better spatial resolution optical observations with the HST (Chu et al. 1999) revealed the existence of faint and diffuse cloudlets located all over the boundaries of the SNR. Some of these cloudlets show radial density gradients suggesting cloud evaporation. Thus, it is possible that the optical emission of S8 is also due to evaporating cloudlets shocked by the primary blast wave of the SNR that produces the X-ray emission. It is also possible that S8 is the remnant of a supernova (SN) explosion inside a superbubble (in this case, the superbubble R9) as Lozinskaya and collaborators pointed out. This fact could also explain the unusual shape of the SNR's emissions. However, how could a dense fragment remain inside the superbubble?. Why we do not see the interaction with the dense shell?.

Our kinematic data in the lines of Hα and [SII](λ = 6731 Å) allows to obtain the radial velocity field of this SNR. We extracted radial velocity profiles for each pixel (equivalent to 1$''$.19 for Hα observations and to 2$''$.38 for [SII] observations) of the SNR and neighboring regions. Typical SNR radial velocity profiles, in Hα and [SII], are shown in Figure 4. These profiles are complex and, consequently, imply the existence of several components at different velocities. We made a profile fitting of two or more Gaussian functions as already described in Paper II. In general, the accuracy in the peak velocities of single velocity profiles is better than ± 4 km s^{-1} while the error in the FWHMs of about ± 3 km s^{-1}. In this case, the accuracy in the determination of the peak velocities of the several velocity components and the error in the FWHMs are not as good as in the case of the single profiles because of the complexity of the velocity profiles and the broadening of the different velocity components. We have estimated the errors in the determinations of the peak velocities and FWHMs by averaging the obtained values of these quantities in several alternative profile decompositions of the same velocity profile. In this way we obtain that, for the more complex profiles, the errors in the determination of the peak velocities of the different velocity components are of about ± 12 km s^{-1} while the errors in the

FWHMs are of about ±15 km s^{-1}.

The radial velocity field of S8, obtained from our FP observations, is shown in Figure 5. In this figure we have marked the main components, product of our profile fitting. We have also marked the boxes over which the velocity profiles were integrated. In addition to the main components, we also detect high velocity gas, red and blueshifted relative to the HII region velocity. As Lozinskaya et al. (1998) have already found, the intensity of these components is about 10 to 20 percent of the intensity of the main components. Also, for the high velocity gas, there is no clear expansion pattern.

The Hα velocity profiles show the presence of gas at the heliocentric velocities between –234 ±12 km s^{-1} and –253 ±12 km s^{-1}. The FWHM of this component is of about 66 ±10 km s^{-1}. This gas reaches almost the heliocentric velocity of the HII gas of the galaxy that, in the neighborhood has velocities between –235 ±4 and –242 ±4 km s^{-1}. The intensity of this component varies between 4.98×10^{-5} to 1.67×10^{-4} ergs cm^{-2} s^{-1} sr^{-1}. A second component, much broader, has velocities between –317 ±12 and –342 ±12 km s^{-1}. The FWHM of this component varies from 66 ±15 to 132 ±15 km s^{-1}. The intensity of this component varies between 2.51×10^{-5} to 2.1×10^{-4} ergs cm^{-2} s^{-1} sr^{-1}.

This component corresponds to Lozinskaya's et al. (1998) main component but we find that the FWHM is about half of the value reported by those authors well above the error of ±15 km s^{-1} estimated for this quantity. In addition, we do not detect a gradient in the heliocentric velocity of the main component (at about –300 km s^{-1}) across the SNR's minor axis as Lozinskaya et al. (1998) do. On the other hand, the broadening of this component is higher at the photometric center of S8 and to the north and west of the center but no clear expansion pattern is appreciated. The [SII] velocity profiles show the same features described above.

All these data, collected by us and by the authors cited before, suggest that S8 could be formed by the interaction of a primary blast wave with a dense clump of large dimensions. The optical emission of S8 is probably due to the radiative shock induced in the clump according to McKee & Cowie (1975) scenario. In this context, the broadening of the velocity profiles is a measure of the velocity of the shock induced in the dense cloud. A typical value of the full width at zero intensity (FWZI) of the main components of the velocity profiles (i.e., without taking into account the components at high velocities) is of about 380 km s^{-1} implying induced shock velocities, V_c, of 170 km s^{-1} for the dense material where the main velocity components discussed above are emitted. This value is in agreement with the velocity values obtained by Lozinskaya and collaborators for the bright emitting gas and with the value derived by Peimbert et al. (1988) from the emission line spectrum. The X-ray emission is due to the heating of the less dense gas where the primary blast wave is propagating at larger shock velocities as described by Lozinskaya et al. (1998). An estimate of the preshock density, n_0, could be derived from the electron density obtained from the observed [SII] 6717/6731 line-ratio, n_e[SII] – an estimate of this quantity from the observed Hα flux of the SNR is not reliable because of the poor angular resolution of all ground based observations carried out till now.

Thus, in order to estimate the preshock density we use the fit to the Raymond's (1979) radiative shock models:

$n_e[SII] = 31.48\ n_0\ (V_s/100 \text{ km s}^{-1})^2$

(Cantó, private comm.) where n_e[SII] and n_0 are expressed in units of cm^{-3} and V_s, the shock velocity, is expressed in units of km s^{-1}. Using our derived value for V_c as V_s and taking n_e[SII] = 1300 - 1500 cm^{-3} (corresponding to the values of the electron density obtained by Lozinskaya et al. 1998 and Peimbert et al. 1988, respectively), we obtain n_0 = 14 - 16 cm^{-3}. This estimate for the preshock density should be considered as an upper limit because it is based only on the spectroscopy of the brighter (and denser) cloudlet of S8.

We can also obtain an upper limit to the energy released by the SN into the interstellar medium, E_0, by substitution of the adopted values: R_s = 12 pc, V_s = 170 km s^{-1} and n_0 = 15 cm^{-3} in the Sedov's relation $E_0 = 1.37\ 10^{42}\ n_0\ V_s^2\ R_s^3$ (Cox 1972), where E_0 is in ergs, n_0 is in cm^{-3}, V_s is in km s^{-1} and R_s is in pc. We obtain $E_0 = 1.0\ 10^{51}$ ergs. This estimate fall within the typical ranges of E_0 in supernova explosions (from 10^{50} to a few 10^{51} ergs).

If S8 were the brightest part of a larger SNR which extends further to the NE till the obscured rim at the boundary of R9, the average preshock density should be lower than the assumed one while the radius should be 3 times larger. It would still be possible to obtain energy values typical of SN explosions. The age, if this latter assumption were right, would be 3 times

longer than the value of (3 - 6) 10^3 yr estimated by Lozinskaya et al. (1998).

A better understanding of this SNR requires: a) radio continuum observations of high sensitivity in a field of at least 30″ centered at the S8 position in order to try to detect a complete shell of non-thermal radio emission, b) better angular resolution images and spectra at optical wavelengths, ideally with the HST.

In conclusion, S8 is a SNR evolving in a clumpy medium where active star formation and stellar winds of massive stars form large superbubbles. Its strange morphology in different wavelengths could be due either to the interaction with a pre-existing superbubble, as Lozinskaya et al. (1998) have suggested, or to the fact that only the brightest region of a larger SNR shell is detected, as suggested in this work. In either case, the primary blast wave, moving at a velocity of thousands of km s^{-1} in a rarefied medium, induces radiative, secondary shocks in more dense clumps that produce the optical emission.

4. The Wolf Rayet star embedded in the HII region S3.

This Wolf-Rayet (WR) star was discovered by d'Odorico & Rosa (1982) and later on it appeared in the list of eight stars in IC 1613 that Armandroff & Massey (1985) considered as candidates to WR stars. It was the number 6 in this list (WR6). Subsequent studies (Azzopardi et al. 1988) have shown that only WR6 is indeed a WR star, while the other candidates were classified as massive supergiants of spectral types ranging from OB to A. Thus, WR6 (according to the nomenclature of Armandroff & Massey 1985) seems to be the only known WR star in IC 1613. This WR is located in the HII region S3 in Sandage (1971), named V37 in Hodge (1990) and N9 in Paper II. This star has also been studied by Davidson & Kinman (1982), Massey et al. (1987), Lequeux et al. (1987) and Kingsburgh & Barlow (1995) while the nebula associated with this WR star has been studied by Goss & Lozinskaya (1995) and Afanasiev et al. (2000).

Kingsburgh & Barlow (1995) classified this star as an oxygen WR star, WO. There are only 5 stars known in the Local Group belonging to this class and WR6 is the brightest member of this class. This class of WR stars constitute a sequence different from the WN and WC sequences, and represents the late stages of very massive ($M_* > 40\ M_\odot$) stellar evolution where He and C burning is taking place at the stellar core. Taking into account that this WO star is inside the nebula S3 and, that it could be the most important source of ionization of two of the superbubbles catalogued in Paper II: R16 and R17, we undertook the detailed study of the interstellar medium (ISM) in the vicinity of this star, mainly of its kinematics, with the aim of knowing more about the interaction of this massive star with its surrounding ISM.

In our field, S3 - the HII region associated with WR6 - is well resolved and located at the southern part of the NE region of IC 1613 at the position (1950): 1 02 27.3 and +01 48 17 (Armandroff & Massey 1985). Its observed equivalent diameter is 253.6 pc (see the definition in Paper II). According to Hodge et al. (1990), S3 is composed of 5 HII regions (a-f).

S3 is located near the southern border of our 10′ field as it is shown in Figures 1 and 2. Figure 6 shows a close-up of the monochromatic Hα image shown in Paper II. In this figure, the morphology of S3 looks spectacular; it seems to be interacting with at least a couple of superbubbles: R17 that is located at its NW side and R16 farther away. On the other hand, its shape recalls a large bipolar nebula, having the WO star at its center, like the galactic planetary nebula NGC 2346 (Arias et al. 2000). In this context, the nebula S3 itself would be the central part of a bipolar structure whose NW lobe encompasses the superbubbles R17 and R16.

In Paper II we have discussed that the superbubbles R16 and R17 are probably linked to the stellar associations H8 and H9 (Hodge 1978). By applying the same automatic method described in Paper I, the new boundaries of the stellar associations are outlined (Borissova et al. 2001). As in the case of the NE region (Paper I), the Hodge (1978) associations H8 and H9 divide into several smaller groups. The 'new' associations in the region are located almost coincident with the superbubbles. As illustrated in Figure 6, the associations are located within or at the peripheries of the superbubbles' boundaries. This suggests that the winds of the massive stars of the interior associations have probably formed these superbubbles and that the associations found at the periphery were formed by the self-induced star formation mechanism. However, the ionizing flux of the close WO star could also contribute to the ionization of these superbubbles. It is interesting to note that the WO star does not belong to any of the stellar associations currently

identified.

Figure 7 and Figure 8 present the Hα velocity maps where the S3 complex shows some emission. Both figures are derived from the same data, but the velocity maps shown in Figure 8 were smoothed both spectrally and spatially and the contrast has been lowered in order to enhance the visibility of the faint filaments located at the NW of S3. The superbubbles R16 and R17 of Paper II (whose boundaries are marked in Figure 6) come to be noticed in some of the velocity maps of Figure 8. As one can see in Figure 7, S3 is composed of two lobes (NW and SE) sorting out from a bright waist which appears like a continuation of the NW lobe. In fact, it appears that the waist, that hosts the WO star in its brightest region, is not a torus (unless it is seen perpendicular to the line of sight). The SE lobe shows more filaments and knots than the NW one and its dimensions are about half of the dimensions of the NW lobe. The NW lobe ends in its brightest region, in the waist. In its brightest region, it appears as an incomplete ellipse, but we cannot see from these velocity maps if it is closed or open. The NW lobe appears crossed by the superbubble R17 while the superbubble R16 is located outside of it. The waist has a small bubble-like feature (hereafter called Bubble A) at its SW end of dimensions: $13''.2$ x $9''.2$. In Figure 8 the details of the internal structure of S3 are not seen because we favored to show the quite faint external superbubbles.

Figure 9 shows the [SII] (λ 6731 Å) velocity maps of the same region. In this figure, there is no evidence of the superbubbles R17 and R16. Most of the [SII] emission corresponds to the bipolar structure internal to S3. For the first time, we detect the NW lobe closed (see the velocity map at V_{HEL} = –233 km s^{-1}). This fact allows us to have a better knowledge of the dimensions and shape (not exactly elliptical but in the form of a clover leaf) of the NW lobe. The SE lobe is as faint as the NW lobe. The Bubble A, at the end of the waist, is also detected. The dimensions of the different regions are: $60'' \times 50''$ or 214 pc $\times$ 179 pc for the NW lobe, $34'' \times 16''$ or 122 pc $\times$ 60 pc for the SE lobe and $22'' \times 12''$ or 81 pc $\times$ 45 pc for the dimensions of the waist. In all these determinations we have adopted the distance to IC 1613 as 725 kpc, as mentioned in the Introduction. The NW lobe is better appreciated in the velocity maps corresponding to V_{HEL} from –233 to –213 km s^{-1} implying that the systemic velocity of the bipolar structure must fall within these velocity values.

In order to study the kinematics of the lobes we have obtained Hα and [SII] radial velocity profiles integrated over boxes of 10 $\times$ 10 and 5 $\times$5 pixels, respectively, covering the S3 complex. Scanning Fabry-Perot observations allow to identify the possible contamination of the radial velocity profiles by possible emission line stars seen projected in the same direction than the integration boxes. We have analyzed this possibility; such a profile could be identified easily because, in that case, the continuum emission of the star would also affect the level of the continuum of the profile. In addition, the effect of an emitting line star would affect only one of the points of the obtained 2-D velocity field and, consequently, it is also possible to identify any abrupt change in the velocities of the velocity components due to this possibility. Except for one velocity profile where the continuum level was higher, we did not find that this effect was relevant in our velocity determinations.

The Hα velocity profiles of the brightest regions are, in general, simple and can be fitted by a single Gaussian function of FWHM, varying between 66 and 81 km s^{-1} and peak velocities ranging from V_{HEL}= –223 $\pm$8 km s^{-1} to –243 $\pm$8 km s^{-1}. The main source of errors for this region is the contamination by the OH night-sky lines that becomes important given the faintness of the emission.

There are regions where some splitting of the velocity profiles appear. One corresponds to Bubble A where at least two velocity components appear (–215 $\pm$10 km s^{-1} and –267 $\pm$10 km s^{-1}) indicating a possible local expansion of more than 26 km s^{-1}. The other one is the region located where the NW lobe closes. In this region, there is splitting in the velocity profiles that can be fitted by two velocity components at –233 $\pm$10 km s^{-1} and –194 $\pm$10 km s^{-1}. Unfortunately, most of the regions interior to the NW lobe are so faint that it was impossible to get any reliable profile decomposition. The values of the velocity components found suggest an expansion motion of the end of the lobe. The component at –226 km s^{-1} can be interpreted as the component of the HII region at rest (at the systemic velocity of the galaxy) while the component at –194 km s^{-1} could be due to the blueshifted region of the lobe. In that case, the expansion velocity at the very end of the NW lobe would be: $V_{blue} - V_{sys}$ = 39 km s^{-1} without any correction for a possible inclination of the bipole axis. This value is smaller than the 75 km s^{-1} value reported by Afanasiev et al. (2000) for the expansion velocity of the NW lobe, but

it still implies a kinematic age of the nebula (2×10^6 yr) of the same order of magnitude.

The [SII] velocity profiles are faint and, consequently, no reliable velocity profile decomposition could be done. Nevertheless, at the end of the NW lobe a single profile shows a heliocentric velocity of –190 km s^{-1} confirming the blueshifted value found in the $H\alpha$ velocity profile of this region.

Figure 10 shows a close-up of the map at $V_{HEL}= -233$ km s^{-1} in [SII] where the features discussed above are better appreciated. Superimposed on this figure we have marked the boxes over which we have extracted the velocity profiles and we also show the obtained radial velocity field at Hα. We have also constructed integrated position-velocity diagrams from our $H\alpha$ and [SII] data cubes. Figure 11 shows the $H\alpha$ position-velocity diagrams and the areas over which they were integrated, both for the S3 complex and a region of IC 1613 where no detectable nebular emission is present.

In the first case, we obtain the position-velocity diagram of the S3 complex and in the second case we obtain the position-velocity diagram of the night-sky lines. A subtraction of them results in a position-velocity diagram free of night-sky contamination. The results of this subtraction are shown in Figure 12.

As we can see from this figure, the velocity width is higher in the waist (200 km s^{-1}) than in the lobes (150 km s^{-1} for the NW lobe and 100 km s^{-1} for the SE one). This contradicts the results of Afanasiev et al. (2000) that find similar values for the waist but widths of up to 330 and 390 km s^{-1} for the SE and NW lobes respectively, i.e., larger velocity widths for the external regions. This contradiction could be due to a higher sensibility of the observations of Afanasiev et al. (2000) that allows to detect the tenuous fast moving regions of the lobes while we are only detecting the brightest and slowest regions. However, it would be interesting to examine their data by means of position-velocity diagrams similar to the ones obtained in this work. It is interesting to note that Afanasiev and collaborators reported an expansion velocity of the NW lobe of 75 km s^{-1} whereas their reported velocity widths in this region reach 400 km s^{-1} implying induced shock velocities of 200 km s^{-1}. Unless there is an inclination correction (inclination of the axis of the bipolar structure relative to the line of sight of about 70 degrees) it is difficult to reconcile the differences between the expansion velocity and the velocity widths quoted by those authors.

Is the nebular complex S3 a bipolar nebula or a blister? In the first case, the lobes would be shaped by an internal mechanism that favors asymmetric ejections and that focuses the ejected gas. In the blister case, the shape would be due to inhomogeneities in the ISM density. For example, one of the 'lobes' would be larger because it could be formed by the stellar winds propagating in a region of decreasing ambient density. The fact that the brightest region is located in a place where there is an HI density gradient, as Afanasiev and collaborators have suggested, argues in favor of the blister possibility. Furthermore, the geometrical models of bipolar structures, developed in Arias et al. (2000), show that even if we see an inclined bipolar nebula, the dimensions of the lobes remain the same, so that the more plausible explanation for the different dimensions of the lobes is that the NW lobe corresponds to the propagation of a shock in a less dense medium. This scenario could be verified by determining the electron densities of both lobes. We have tried to do so by means of the surface brightness measurements reported in Table 1, but our results are quite uncertain because the NW lobe emission is not easily disentangled from the emission of the superbubble R17.

5. Conclusions

- We study the kinematics of the SNR S8, in the galaxy IC 1613, taking into account its environment rich in superbubbles. The SNR S8 appears located at the boundary of the superbubble R10 (according to Paper II's notation) and is seen in projection within superbubble R9. Between the superbubbles R9 and R4, a ridge of obscured material is detected suggesting the presence of dust in the vicinity of this SNR.

- We discuss the optical appearance of this SNR that does not show the classical filamentary shell characteristic of SNRs; instead, in the visible, radio and X-rays, it shows several of the characteristics of a plerionic-type SNR. We give several arguments against this possibility and suggest that we are seeing only a part of a shell-type SNR.

- We obtain the radial velocity field of the optical counterpart of this SNR. We find that the velocity profiles are complex, revealing the presence of several velocity components. The brighter component is at the velocity of neighboring HII regions and has FWHM of about 66 $\pm$10 km s^{-1}. A broader (FWHM between 66 $\pm$15 to 132 $\pm$15 km s^{-1}) blueshifted ve-

locity component is also identified. However, the velocity widths we find are about half of the values reported previously by Lozinskaya et al. (1998). Also, we do not find the velocity gradient that Lozinskaya and collaborators report for this component. Our velocity profiles also show the presence of high velocity gas of low density. In agreement with Lozinskaya et al. (1998) we do not find a clear sign of an expansion pattern.

- Assuming that the optical emission comes from the interaction of a primary blast wave with a dense clump of large dimensions, we were able to derive the velocity of the shock induced in the clump from the FWZIs of the velocity profiles. We find a value of 170 km s^{-1} for this shock velocity and we estimated the preshock density, the energy released by the supernova and the kinematic age of this SNR. We explore the possibility mentioned before that this SNR could be only a part of a large diameter shell-type SNR hidden by dust and we find that the energetics is compatible with this hypothesis. However, the possibility that this SNR has a weird appearance due to the interaction of SN ejecta with a pre-existing cavity cannot be ruled out with the existing data.

- We find that the S3 complex (formed by the bright HII region catalogued by Sandage 1971 and several filaments) is constituted of a bright central region hosting in its center the WO star and two lobes oriented in the NW-SE direction, being the NW lobe longer than the SE lobe.

- We find from the [SII] FP observations that the NW lobe is closed and has a clover leaf shape; its major axis is 214 pc long, while the SE lobe is more filamentary and has a major axis of 122 pc.

- We have also found that the superbubble R17 in Paper II is seen in projection towards the NW lobe, while the superbubble R16 is located near the end of the NW lobe. These superbubbles have in their interiors and at their boundaries several stellar associations (Borissova et al. 2001) and it is probable these superbubbles are formed by the winds of the massive members of the stellar associations in spite of the close presence of the WO star. On the other hand, the WO star could be ionizing the superbubbles and thus, making them detectable.

- We study the kinematics of this bipolar nebula finding some evidence of a possible expansion motion of the NW lobe at 40 km s^{-1}, if an inclination correction is not important. This value is 50 % lower than the one reported by Afanasiev et al. (2000) but, in any case, neither of those values imply a kinematic age in agreement with the duration of the WR phenomena (a few 10^5 years), and even less with the much shorter duration of the WO phase. However, the privileged position of the WO star is the main argument in favor that its progenitor has formed this peculiar nebula.

- Our position-velocity diagrams of the S3 system show that the velocity widths are larger in the central waist than in the lobes. This contradiction with Afanasiev's et al. (2000) results could be due to a probable lower sensitivity of our observations.

At last, even if these nebulae (S8 and S3) were formed by only one star in each case, the influence of those stars upon the ISM of IC 1613 is quite remarkable.

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Fig. 1.— Hα velocity map at the heliocentric velocity of –253 km s^{-1} of the central region of the galaxy IC 1613. The locations of the selected nebulae studied here are clearly marked. The orientation and the scale are indicated up and down to the right, respectively.

Fig. 2.— Idem but for the [SII](λ 6731 Å) line. Note that the Hα velocity map has a better spatial resolution ($1''.18$ px^{-1}) compared with the [SII] one ($2''.36$ pix^{-1}).

Fig. 3.— Close-up of the SNR S8 Hα emission. The isophotes show the elongated form of the SNR. Part of the HII region S7 is seen to the north. The orientation and the scale are indicated.

Fig. 4.— Typical radial velocity profile of the SNR S8 at Hα (upper case) and at [SII](λ6731 Å) (lower case). For the [SII] profile, the secondary peak corresponds to the [SII] (λ6717 Å) line.

Fig. 5.— Radial velocity field of the SNR S8. The square boxes correspond to the regions over which the integration was done in order to extract the velocity profiles. Only the main components of the profile fitting are shown.

Fig. 6.— Close-up of the field around the nebula S3 showing the position of the stellar associations found in Borissova et al. (2001) superimposed onto the limits of the superbubbles R12, R16 and R17. Likewise the spatial position of the WO star is indicated. The orientation and the scale are also indicated.

Fig. 7.— Hα radial velocity maps of the S3 complex (high contrast). The numbers appearing in the lower left corner of each map correspond to the heliocentric velocities.

Fig. 8.— Hα radial velocity maps of the S3 complex (low contrast). The superbubbles R16 and R17 discussed in the text, are visible in the velocity maps at V_{HEL}=–272, –253 and –234 km s^{-1}.

Fig. 9.— [SII] radial velocity maps of the S3 complex. The arrow in the map at V_{HEL}=–233 km s^{-1} shows where the NW lobe closes.

Fig. 10.— Radial velocity field of S3 superimposed on the [SII] image map at V_{HEL}=–233 km s^{-1}. The square boxes show the integration areas over which the velocity profiles were extracted. The dashed lines show the appearance of the bipolar nebula. The orientation and scale are indicated.

Fig. 11.— Position-velocity diagrams of the bipolar nebula S3 (left) and of an 'empty' region that gives us the night-sky contaminating emission (right). The images shown in the upper part of this figure show the regions where the position-velocity diagrams were obtained by integrating over their longer axis.

Fig. 12.— Nebular position-velocity diagrams free from night-sky emission, obtained from the subtraction of the position-velocity diagrams shown in Fig. 12. In the upper panel we show the direct image of the bipolar nebula at the same scale.

Table 1

Surface brightness values of the different regions of S3.

Region	S(Hα) ergs cm^{-2} s^{-1} sr^{-1}
NW LOBE	$(2.80 \pm 0.61) \times 10^{-6}$
SE LOBE	$(8.11 \pm 1.95) \times 10^{-6}$
WAIST	$(4.45 \pm 1.0) \times 10^{-5}$